Uptake of Selected Nutrients by Temperate Grasses and Legumes

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ABSTRACT

Temperate forages are used throughout the southeastern USA to provide feed for livestock when tropical and subtropical grasses are dormant and as a hay source. Long-term utilization of broiler litter as a fertilizer in some areas of the region has elevated soil levels of P and micronutrients. Our objective was to compare P, Cu, and Zn uptake among temperate forage species from a Savannah fine sandy loam soil (fine-loamy, siliceous, semiactive, thermic Typic Fragiudult) amended with litter under a single-harvest system. Dry weight of ryegrass (*Lolium multiflorum* Lam.) herbage was greater than all other species except ball clover (*Trifolium nigrescens* Viv.) in 1997 and oat (*Avena sativa* L.) in 1998. Clovers were susceptible to *Sclerotinia* crown and stem rot (*Sclerotinia trifoliorum* Erikss.) that reduced plant density, vigor, and dry herbage weight. Although forage P concentration of all species was similar to or greater than ryegrass, only crimson clover (*T. incarnatum* L.) had P uptake equal to ryegrass during both years (mean of 23.4 kg ha^{-1}). This was attributed to the high correlation between dry herbage weight and P uptake (r = 0.95 and 0.89 in 1997 and 1998, respectively). Legumes typically had greater Cu and Zn concentrations than ryegrass, but only crimson clover and hairy vetch (*Vicia villosa* Roth) had comparatively greater Cu and Zn uptake during both years. The combination of desirable agronomic traits and nutrient uptake capacity make annual ryegrass a superior temperate forage species for use in southeastern pastures fertilized with broiler litter.

Temperate forage species are an integral component of many forage–livestock systems in the southeastern USA. These forages, which include annual ryegrass, annual clovers, small grains, and some perennial species, are planted in late summer or early fall in a prepared seedbed or oversown on a perennial grass sod and grazed during the winter and spring (Bagley et al., 1988). They provide high quality forage during a period when cool temperatures limit tropical and subtropical grass growth. If a hay crop is desired, producers are usually limited to a single harvest in late spring because of frequent precipitation and low temperatures during March and April. Of the available annual forages, ryegrass is the primary temperate species utilized due to its adaptability to a broad range of soil and climatic conditions, ease of establishment, late maturity compared with small grains, excellent forage quality (Balasko et al., 1995), and tolerance of close, continuous stocking (Ball et al., 1991).

The Southeast is also the primary producer of broiler chickens (*Gallus gallus domesticus*) in the USA. Approximately 70% of the broiler chickens produced nationally in 1999 were produced in Arkansas, Georgia, Alabama, Mississippi, North Carolina, Texas, Tennessee, and South Carolina (Natl. Agric. Statistics Serv., 1999). A large proportion of the litter (a mixture of manure, wasted feed, feathers, and wood shavings or other crop residue) is applied to hay fields and pastures. Litter application may occur anytime during the year, depending on when a flock is removed from the house. If litter is applied to a dormant perennial or dead annual tropical grass hay field or pasture during the winter and spring, the presence of an actively growing temperate forage will reduce the potential for P loss, largely by reducing sediment movement in runoff (Sharpley et al., 1994).

Frequent litter application also contributes to the accumulation of P and metals in the soil such as Cu and Zn, which are added to poultry diets to improve weight gain and prevent diseases (Han et al., 2000). A benefit of utilizing temperate species is that when harvested for hay, they provide a means of exporting these minerals from fields where manure is applied (Brink and Rowe, 1999). Temperate forages can thus serve in both a feed and nutrient management role (Daniel et al., 1998) in hay and pasture systems receiving broiler litter as a fertilizer source.

Our objective was to compare P, Cu, and Zn uptake among temperate forage species typically utilized in the region. Although legumes typically have greater P, Cu, and Zn concentrations than grasses (Minson, 1990), herbage yield may have greater influence on nutrient uptake than mineral concentration. Because annual ryegrass is the primary temperate forage used in the region, all species were compared with this species.

MATERIALS AND METHODS

The study was conducted in each of 2 yr on a farm near Collins, MS (31.6° N, 89.6° W) on a Savannah fine sandy loam. The producer applied broiler litter to the pasture in which the study was conducted every 2 to 3 yr at rates ranging from 4.5 to 9.0 Mg ha^{-1} for the past 10 yr. Before plots were established each year, soil samples were collected at 0- to 15- and 15- to 30-cm depth from 16 cores randomly located in the plot area and composited by depth. Soil characteristics using the Mehlich 3 extractant (Mehlich, 1984) are presented in Table 1. Litter (34, 20, and 32 g kg^{-1} N, P, and K, respectively, and 82 and 504 mg kg^{-1} Cu and Zn, respectively) was applied at 9 Mg ha^{-1} and incorporated to 15 cm before seeding. Monthly precipitation during the 2 yr of the experiment is presented in Fig. 1. Mean temperatures for the period were near normal.

In late September 1996 and 1997, 12 temperate legume and four temperate grass species utilized for forage in the southeastern USA (Table 2) were broadcast on a tilled (15-

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Table 1. Soil chemical characteristics at the start of the experiment each year.

Sample depth	pH	P	K	Ca	Cu	Fe	Mg	Mn	Zn
cm		mg kg^{-1}							
1996									
0–15	5.1	55	63	674	12.4	361	68	154	4.6
15–30	5.5	5	49	709	5.6	123	83	72	1.5
1997									
0–15	5.5	62	39	815	12.2	382	75	186	4.2
15–30	5.7	1	26	580	3.8	117	54	98	0.7

cm depth) seedbed and cultipacked. Plots were established each year on separate but adjacent sites. The 2- by 5-m plots were arranged in a randomized complete block design (four replicates) with a 1-m alley separating each replicate. These species are usually grown without efforts to control diseases or insects or adjust soil pH due to the cost of such measures. These species were therefore evaluated without the benefit of these inputs. In practice, climatic conditions usually permit only a single hay harvest. All species were treated as annuals and harvested once the following spring when legumes were at full bloom and grasses were at dough stage.

To reduce the variability between replicates due to irregular establishment of subterranean clover (*T. subterraneum* L.), caley pea (*Lathyrus hirsutus* L.), and winter pea [*Pisum sativum* var. *arvense* (L.) Poir.] both years, herbage yields were determined by cutting a 1.0-m^2 quadrat from each plot at a 2.5-cm stubble height. The remainder of the plot was sampled to determine nutrient allocation among plant morphological components (Pederson et al., 2001). The harvested sample was dried at 65°C for 48 h, weighed, and then ground to pass a 1-mm screen. A 50-g subsample of the ground forage was stored in plastic bottles.

Herbage P, Cu, and Zn concentrations were measured by the following procedure: A 1-g subsample was ashed at 500°C for 4 h, and then 1.0 mL of a 1:1 solution of hydrochloric acid (aqueous HCL) and distilled water was added to the crucible. After 1 h, 50 mL of a double acid solution [83 mL hydrochloric acid and 14 mL sulfuric acid (H_2SO_4) brought to 20 L with distilled water] was added to the crucible, allowed to stand for 1 h more, and then filtered. Phosphorus, Cu, and Zn concentrations of the filtrate were measured by emission spectroscopy on an inductively coupled Ar plasma spectrophotometer. Nutrient uptake was calculated as a product of the dry herbage weight and forage P, Cu, and Zn concentration. A significant ($P \leq 0.05$) dry herbage weight × year interaction dictated that years be analyzed separately. Single degree-of-freedom contrasts ($P \leq 0.05$) between ryegrass and each of the other 15 species were used to determine dry herbage weight, nutrient concentration, and nutrient uptake differences.

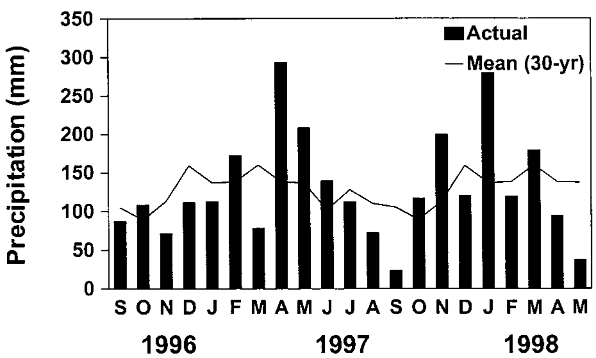

Fig. 1. Actual and mean (30 yr) monthly precipitation during the experiment at Collins, MS.

Table 2. Temperate legumes and grasses established near Collins, MS.

Common name	Scientific name	Seeding rate (kg ha^{-1} pure live seed)
Ryegrass	*Lolium multiflorum* Lam.	33.6
Small grains		
Oat	*Avena sativa* L.	100.8
Rye	*Secale cereale* L.	100.8
Wheat	*Triticum aestivum* L. emend. Thell.	100.8
Clovers		
Arrowleaf	*Trifolium vesiculosum* Savi	11.2
Ball	*T. nigrescens* Viv.	3.4
Berseem	*T. alexandrinum* L.	22.4
Crimson	*T. incarnatum* L.	22.4
Persian	*T. resupinatum* L.	3.4
Red	*T. pratense* L.	9.0
Rose	*T. hirtum* All.	22.4
Subterranean	*T. subterraneum* L.	22.4
White	*T. repens* L.	4.5
Other legumes		
Caley pea	*Lathyrus hirsutus* L.	56.0
Winter pea	*Pisum sativum* var. *arvense* (L.) Poir.	44.8
Hairy vetch	*Vicia villosa* Roth	28.0

RESULTS AND DISCUSSION

Dry Herbage Weight

Annual ryegrass yielded greater dry herbage than all other species except ball clover in 1997 and oat in 1998 (Table 3), confirming previous reports of consistent, superior forage production compared with other fall-sown, temperate species (Edwards et al., 1996). Growth of many species was greatly impacted by weather. Dry herbage weight of oat, rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.) was approximately twofold greater in 1998 than in 1997 because germination and early growth were improved by above-average precipitation in October and November 1997 (Fig. 1). Clover growth was improved in the fall of 1997 as well, but weather conditions in January 1998 (above-average precipitation and favorable temperatures) contributed to the development of *Sclerotinia* crown and stem rot in ball, berseem (*T. alexandrinum* L.), crimson, Persian (*T. resupinatum* L.), red (*T. pratense* L.), rose (*T. hirtum* All.), and white clover (*T. repens* L.). Plant density and vigor of remaining plants were reduced despite the high fertility status of the soil (Marschner, 1995). The potential for development of this disease is greater in swards that remain uncut through the winter (Pratt, 1991), and this represents a disadvantage of these species when managed in this manner. *Sclerotinia* crown and stem rot symptoms were not apparent in arrowleaf (*T. vesiculosum* Savi) and subterranean clover (Pratt and Knight, 1984).

Herbage Nutrient Concentration

Phosphorus concentration of all forage species relative to ryegrass varied greatly between the 2 yr. In 1997, the P concentration of oat, rye, and wheat exceeded that of ryegrass (Table 3), possibly as a result of the dry conditions that existed during small-grain maturation, which could increase herbage P concentration compared with wet conditions (Payne et al., 1995). Except for subterranean clover, white clover, caley pea, and hairy

Table 3. Dry herbage weight, P, Cu, and Zn concentration of temperate grasses and legumes.

	1997				1998			
	Dry wt.	P	Cu	Zn	Dry wt.	P	Cu	Zn
	kg ha^{-1}	g kg^{-2}	mg kg^{-2}		kg ha^{-1}	g kg^{-2}	mg kg^{-2}	
Ryegrass	12 400	2.3	2	17	10 000	1.8	2	19
Small grains								
Oat	3 950*	3.2*	2	16	9 420	2.3	2	18
Rye	3 440*	3.2*	4	21	6 180*	2.3	3	19
Wheat	2 880*	3.3*	2	27	6 000*	2.4	3	21
Clovers								
Arrowleaf	6 260*	2.4	6*	32*	5 240*	2.3	6	29
Ball	11 040	2.7	5*	30	4 400*	3.1*	7	40*
Berseem	4 720*	2.6	9*	43*	870*	2.3	10*	63*
Crimson	9 720*	2.9	6*	32*	5 380*	3.0*	8*	39*
Persian	1 900*	2.3	12*	39*	800*	2.9*	10*	74*
Red	9 190*	2.8	8*	25	5 040*	2.5*	6	29
Rose	5 100*	2.7	7*	34*	3 620*	2.8*	8*	63*
Subterranean	2 460*	3.2*	12*	65*	3 650*	3.5*	13*	58*
White	2 740*	3.4*	6*	31	1 480*	4.1*	20*	61*
Other legumes								
Caley pea	1 940*	3.0*	19*	84*	2 690*	3.3*	13*	58*
Winter pea	2 640*	2.6	11*	61*	3 420*	3.8*	10*	48*
Hairy vetch	5 480*	3.4*	8*	56*	5 580*	3.3*	8*	53*

* Significantly different from ryegrass at $P \leq 0.05$.

vetch, the P concentration of the legumes was similar to that of ryegrass. In 1998, however, the P concentration of all clovers except arrowleaf and berseem and the other legumes was greater than that of ryegrass while P concentration of the small grains was similar to that of ryegrass. These results are more typical of those reported by Minson (1990), whereby the P concentration of legumes exceeds that of temperate grasses.

Unlike P concentration, differences in Cu and Zn concentrations between ryegrass and the other temperate forages were more consistent between 1997 and 1998. Clovers and other legumes usually had greater Cu and Zn concentrations than ryegrass (Minson, 1990; Table 3) while the Cu and Zn concentrations of the small grains were similar in both years.

Herbage Nutrient Uptake

Nutrient uptake is the product of herbage yield and the nutrient concentration of the herbage. Despite the variation in dry herbage weight and P concentration among species and between years (Table 3), P uptake by ryegrass was greater than most species in both years (Table 4). Only crimson clover had uptake equivalent to ryegrass in both 1997 and 1998. Where P uptake of another species was equivalent to that of ryegrass in a particular year, these species had dry herbage weights equal to or nearly equal to ryegrass and equivalent P concentrations (ball clover, crimson clover, and red clover in 1997 and oat in 1998). Phosphorus uptake was highly correlated ($P \leq 0.001$) with dry herbage weight ($r = 0.95$ and 0.89 in 1997 and 1998, respectively) while there was a negative or low correlation between P uptake and herbage P concentration ($r = 0.12$ and -0.11 in 1997 and 1998, respectively). In just two cases (crimson clover and hairy vetch in 1998), high herbage P concentration compensated for low dry herbage weight to produce P uptake equivalent to ryegrass. The superior P uptake of ryegrass compared with other species can be attributed to this positive association between dry herbage weight and P uptake. Average P uptake by ryegrass (23.4 kg ha^{-1}) was less than its reported potential of approximately 34 kg ha^{-1} (Robinson, 1996) probably because not all of the N in the litter would be mineralized and available during the growing season. This uptake, however, would constitute approximately 25% of the total P removed annually by hay when bermudagrass [*Cynodon dactylon* (L.) Pers.] fertilized with broiler litter at 9 Mg ha^{-1} is oversown with annual ryegrass (Brink and Rowe, 1999).

Although Cu and Zn concentrations of the clovers and other legumes usually exceeded that of ryegrass (Table 3), only crimson clover and hairy vetch had greater Cu uptake than ryegrass while only hairy vetch had greater Zn uptake than ryegrass in both 1997 and 1998 (Table 4). Copper and Zn uptake by ryegrass was greater than that of the small grains in both years. The correlation between Cu and Zn uptake and dry herbage

Table 4. Phosphorus, Cu, and Zn uptake by temperate grasses and legumes.

	1997			1998		
	P	Cu	Zn	P	Cu	Zn
	kg ha^{-1}	g ha^{-1}		kg ha^{-1}	g ha^{-1}	
Ryegrass	28	29	208	19	22	196
Small grains						
Oat	13*	8*	63*	21	22	172
Rye	11*	12*	71*	14*	18	117*
Wheat	10*	7*	79*	14*	19	128
Clovers						
Arrowleaf	15*	37	198	12*	31	153
Ball	29	53*	331*	13*	30	174
Berseem	12*	42*	202	2*	8	55*
Crimson	28	53*	317*	16	44*	209
Persian	4*	22	72*	2*	7	56*
Red	26	68*	225	12*	31	142
Rose	14*	33	172	10*	30	229
Subterranean	8*	30	160	13*	48*	217
White	9*	18	85*	6*	30	90*
Other legumes						
Caley pea	6*	37	158	9*	36	152
Winter pea	7*	30	181	13*	34	168
Hairy vetch	19*	44*	303*	18	48*	302*

* Significantly different from ryegrass at $P \leq 0.05$.

weight was not as great as that for P uptake and dry herbage weight but was significant ($P \leq 0.05$) in both years ($r = 0.62$ and 0.24 for Cu in 1997 and 1998, respectively, and $r = 0.69$ and 0.55 for Zn in 1997 and 1998, respectively).

CONCLUSIONS

The use of temperate annual grasses or legumes in warm-season, perennial grass systems utilizing broiler litter as a fertilizer source represents an opportunity to produce high quality forage for livestock, reduce potential nutrient loss to the environment by runoff, and remove nutrients added to the system by the litter through hay production. For many forage and/or livestock producers across the southeastern USA, annual ryegrass has been the temperate forage most frequently used because of its ease of establishment and consistent productivity. Our results confirmed its superior yield compared with other commonly available temperate species when grown under a single-harvest system without the benefit of disease or insect control. Although ryegrass herbage P concentration was equivalent to or less than that of three small grains and 12 legumes, only crimson clover removed as much P as ryegrass in each of the 2 yr that the experiment was conducted. With few exceptions, ryegrass had greater uptake of the minor nutrients Cu and Zn as well, indicating that dry herbage yield was the primary determinant of mineral uptake in these species. Although the mineral uptake of ryegrass did not constitute a large portion of that applied in broiler litter (<20%), the combination of superior agronomic performance and nutrient uptake suggest that annual ryegrass is the best choice where temperate annual forages are fertilized with broiler litter and utilized as a grazed or preserved feed source.

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